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Research and Development Report

USNS HAYES (T–AG 195) Results of Standardization Trials

by
Michael L. Klitsch

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Standardization trials were conducted off the coast of La Jolla, CA from 23 through 25 October 1992 in sea states 0–1.

Standardization results showed that HAYES achieved maximum powering conditions of an average shaft speed of 121.3 r/min, a total shaft torque of 108,800 lb–ft (147,500 N–m) and a total shaft horsepower of 2,510 (1,870 kW) with a speed of 12.36 kn at a displacement of 3,898 tons (3,960 t) and trim by stern of 12 in. (30.5 cm).

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ABSTRACT

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ADMINISTRATIVE INFORMATION

As of January 1992, the David Taylor Research Center (DTRC) became the Carderock Division, Naval Surface Warfare Center (CARDEROCKDIV) located at the David Taylor Model Basin (DTMB). Throughout this report the Center will be referred to as the David Taylor Model Basin (DTMB). The trials described herein were requested by the Naval Sea Systems Command (NAVSEA), PMS 383. This work was authorized by Work Request N0002492WR20819/AA of 4 December 1991. The trials discussed in this report were conducted by DTMB representatives and funded under Work Unit 1925-049.

INTRODUCTION

Standardization, tactical circle, acceleration and deceleration, lateral stability, horizontal overshoot, several towed array maneuvers, and full power trials were conducted on USNS HAYES (T-AG 195) off the coast of California from 17 through 25 October 1992. The objective of the trials was to determine the hydrodynamic characteristics of the ship. The results of the standardization trials are presented in this report.

Preliminary results of all the trials were delivered by DTMB representatives to the ship and sponsor during two post-trials debriefings. At the first debriefing held on 22 October 1992, after the transit from Bremerton, WA, results for the lateral stability, horizontal overshoot, and full power trials were presented. At the second debriefing, held on 26 October 1992 after the trials on range at La Jolla, CA, results for the standardization, tactical circle and acceleration and deceleration trials were presented.

HAYES is an oceanographic research catamaran, formerly USNS HAYES (T-AGOR 16), that has recently been converted for a new mission. This task was accomplished in 1992 at Puget Sound Naval Shipyard, Bremerton, Washington. The new mission is to serve as an acoustic research platform in support of the U.S. Navy's submarine noise reduction program. HAYES replaces

DTMB's aging acoustic research vessel Mobile Noise Barge (MONOB). HAYES' overall length is 246 ft, 5 in. (75.1 m) with a length between perpendiculars of 220 ft, 0 in. (67.1 m). The beam is 75 ft, 0 in. (22.9 m). The design even keel draft is 22 ft, 3.4 in. (6.8 m), and the design full load displacement is 4,037 ton (4,102 t).

The power system for HAYES consists of five diesel generator sets. These five sets are located in two isolated boxes which rest on many sets of inflatable rubber mounts. The ship's propulsion and ship's service load is handled by three of the diesel generator sets. Each of these sets consists of a Caterpillar Diesel Engine (model number 3516 DITA) directly coupled to an 1150 kW (1540 shp) Kato Generator. The ship's laboratory electronics are powered by the remaining two Caterpillar Diesel Engine (model number 3412 DIT) generator sets. These are rated at 320 kW (430 shp).

HAYES is a twin shaft ship equipped with fixed pitch propellers. Each shaft is driven by a Westinghouse 1200 shp dc electric motor. The catamaran has a foil attached between the two hulls forward of the bridge superstructure and below the waterline. HAYES accommodates 74 personnel which includes officers, crew, and scientists.

Table 1 lists the principal ship and propulsion shaft characteristics, and Table 2 lists the principal propeller characteristics for HAYES.

The text of the report is divided into the following sections:

- Instrumentation,
- Trial Conditions,
- Trial Procedures,
- Presentation of Results, and
- Appendixes.

INSTRUMENTATION AND DATA COLLECTION

Trial data were collected from DTMB instrumentation and existing ship signals. The block diagram of the routing of the signals is shown in Fig. 1. A detailed description of the DTMB instrumentation, existing ship signals and a discussion of measurement uncertainty can be found in Appendix A.

As shown in Fig. 1, trial signals were routed from their respective sources to either synchro to analog (S/A) converters or amplifiers. The signals were then channeled into a Hewlett Packard data acquisition unit (HP 3852A). This unit converted analog signals to digital signals. The digital signals from the data acquisition unit were then recorded on 3.5 in. (8.9 cm) disc storage drives (HP 9122) and analyzed with a Hewlett Packard computer (HP 350). Hard copy printouts of the data analysis were provided with an HP line printer.

Shaft torque was obtained by Wireless Data Corporation (WDC) torsionmeters (1645 System) installed by DTMB personnel. These were temporary trial torsionmeters.

Figure 1 shows a Motorola Falcon 484 pulse radar tracking system and a Global Positioning System (GPS); both were interfaced with DTMB instrumentation during the trials. The Motorola Falcon 484 pulse radar tracking system provided the ship's position and speed throughout the trials. The ship's speed from the pulse radar tracking system is the speed over the ground. The GPS position and speed data (GPS also provides speed of the ship over the ground) were collected throughout the trials for later DTMB analysis and evaluation.

TRIAL LOCATION AND CONDITIONS

HAYES was in drydock for hull painting at Puget Sound Naval Shipyard (PSNY) from 11 July 1991 until 20 August 1991. The boot topping, bottom, rudders, and struts were taken down to near white by abrasive blast. The following paints, (manufactured by International Paint Company) were sequentially applied: KHA 302 Gray, KHA 303 Red, KHA 304 Black, BRA 540 Red, and BRA 542 Black. The final two coats are ablative paints with biocide. Both rope guards and all zincs were replaced. Finally, a new WQC-2 sea chest was installed.

HAYES remained in the water at Puget Sound Naval Shipyard (or that vicinity) until embarking for San Diego, CA on 15 October 1992. PSNY diver's conducted a hull inspection on HAYES three weeks prior to the transit. The inspection showed HAYES to be in excellent condition for the trials as it had a clean hull with no grass or barnacle growth.

Lateral stability, horizontal overshoot, several towed array maneuvers, and full power trials were conducted off the coast of California between 17-20 October. Tactical circles and acceleration and deceleration trials were conducted on 24 October off the coast of La Jolla, California.

Standardization trials were conducted on HAYES from 23 through 25 October 1992 off the coast of La Jolla, CA. A diagram of the tracking area at La Jolla is shown in Fig. 2. Geodesic specifics of the tracking site at La Jolla are presented in Appendix B.

Sea states during the trial were ideal and ranged between 0 and 1. True wind speeds were usually less than 10 kn and generally from a southerly direction. Trial site seawater temperature and specific gravity were relatively constant each day of the trials and were measured to be 69°F (21°C) and 1.026, respectively.

Standardization trials were conducted at two specific conditions. A set of standardization trials was conducted at an even keel condition, and a set of standardization trials was conducted at a trim by stern condition. The average ship displacement and trim during each of these trials was determined by using two sets of draft readings, both of which were obtained in San Diego Bay. The first set was obtained after fueling at the fuel pier at the U.S. Naval Supply Center Fuel Annex in San Diego at noon on 23 October 1992. These draft readings were applicable to the even keel standardization trial condition. The second set of draft readings was obtained at the U.S. Naval Supply Center San Diego at noon on 25

October 1992 just before the ship was tied up at the pier. These draft readings were applicable to the Trim by Stern condition. Draft reading site seawater temperature and specific gravity were the same for each day, measurements were taken and were found to be 69°F (21°C) and 1.025, respectively. As shown below the displacement and trim of HAYES for the two specific conditions was:

	Even Keel Trials	Trim by Stern Trials
Date	23 Oct 1992	23 - 25 Oct 1992
Trim by Stern, in. (cm)	1 (2.5)	12 (30.5)
Displacement, ton (t)	3,951 (4,014)	3,898 (3,960)

HAYES attained the even keel condition by topping off the fuel tanks and filling the forward ballast tanks with sea water. Upon completion of the even keel trials, HAYES attained the trim by stern condition by emptying the forward ballast tanks. The ship reported that deballasting the forward tanks yields a 12 in. (30.5 cm) trim by stern condition and 40 tons (40.6 t) less displacement. The data listed above shows a 12 in. (30.5 cm) trim by stern condition and 53 tons (30.5 t) less displacement. These values are in very good agreement with measurement accuracies.

Table 3 presents the various standardization trial conditions observed on the tracking area during the trial period. The details of determining ship's displacement for the even keel condition and the trim by stern condition can be found in Appendix C.

GENERAL TRIAL PROCEDURES

The standardization trials were conducted on a pulse radar tracking range to determine ship's position. Each maneuver was commenced after steady approach conditions were established; this ensured validity of comparison for data analysis. Shaft torque, shaft speed, ship speed, and position were monitored during the buildup for each run.

The DTMB Trial Director was informed by the Officer of the Deck when ship's heading and shaft speed had been brought to the scheduled values. Rudder movements were minimized at this time. The Trial Director and/or computer operator were then responsible for verifying those conditions with DTMB instrumentation. Ship speed was utilized as the final indicator of steady conditions since shaft speed stabilized well before the ship's momentum. The rate of ship speed change was monitored with shipboard DTMB tracking equipment.

Steady approach conditions were maintained for one minute. After this, four minutes of standardization run data were collected. More detailed descriptions of the procedures including a definitive diagram of the standardization maneuver are found in Appendix D.

PRESENTATION AND DISCUSSION OF RESULTS

Results of the trials on HAYES are presented below with graphical and tabulated data used to support discussions. All standardization runs were conducted with:

- Both motors on line,
- Both shafts driving,
- Minimum rudder used.

The results of the standardization trials conducted on HAYES are graphically presented in Figs. 3 through 6 and are tabulated in Tables 4 through 7.

DISPLACEMENT AND TRIM DURING THE TRIALS

Even keel standardization trials were conducted on 23 October 1992 at a displacement of 3,951 tons (4,014 t) and a trim by stern of 1 in. (2.5 cm). These trials evaluated speed/powering characteristics at the even keel operating condition of the ship.

HAYES' trim by stern standardization trials were conducted on 23-25 October 1992 at a displacement of 3,898 tons (3,960 t) and a trim by stern of 12 in. (30.5 cm). A towed array spot was also conducted at this condition. These trials evaluated speed/power characteristics of HAYES in a 12 in. (30.5 cm) trim by stern operating condition.

A third condition for trials at a trim by bow condition was requested. Ship's force responded that the even keel condition (trim by stern of 1 in. [2.5 cm]) was as "bow down" as the ship is capable of achieving.

Ship's force typically operate the ship in a 12 in. (30.5 cm) trim by stern condition.

STANDARDIZATION FIGURES

Figures 3 and 4 are the English and metric standardization curves and show the shaft speed, power, and torque required to achieve a particular ship speed. Figures 5 and 6 represent English and metric plots of torque versus shaft speed. These figures will be used to support discussions on the following observations.

Six standardization speed spots were conducted at even keel on 23 October. The last of these six spots was conducted at full power. Upon completion of these runs, the ship's forward ballast tanks were emptied to provide the trim by stern condition. Upon completion of the deballasting, a maximum speed/power spot was conducted. This point fell virtually on top of the the even keel maximum speed/power spot conducted about two hours previously. On 24 October (about 24 hours after the even keel runs) three trim by stern standardization speed spots were conducted at similar speeds to three of the six even keel spots. One of the trim by stern spots was conducted at full power. All three spots fell on the corresponding even keel spots. These results indicate that the ship's speed/power characteristic is

identical for trims ranging from 1 in. (2.5 cm) trim by stern to 12 in. (30.5 cm) trim by stern and displacements between 3,898 tons (3,960 t) and 3,951 tons (4,014 t).

One speed spot was conducted at the trim by stern condition and with the towed array deployed. About 2,200 ft (671 m) of cable was deployed with a dummy array. The dummy array was designed to have the same drag as the actual array. The data point shows that the ship requires about 23% more power to achieve a given speed or at a given power the ship loses about 0.8 kn speed with the array deployed. Also about 7% more torque is needed to achieve a given shaft speed.

MAXIMUM CONDITIONS

There were three maximum speed/power spots conducted which show data repeatability. The data for these three spots were nearly identical. A detailed description of the uncertainty on these three spots can be found in Appendix A. The maximum speed/power conditions attained for HAYES, at each of the three maximum speed/power spots, are as follows:

	Even Keel	Trim by Stern	Trim by Stern
Trim by Stern, in	1	12	12
Trim by Stern, cm	2.5	30.5	30.5
Date, October	23rd	23rd	24th
Time of Day, hours	1940-2040	2220-2250	2210-2250
Top Speed, kn	12.39	12.36	12.40
Maximum Shaft Speed, r/min	121.2	121.3	121.1
Total Shaft Torque, lb-ft	108,700	108,800	108,300
Total Shaft Power, shp	2,510	2,510	2,500
Total Shaft Torque, N-m	147,400	147,500	146,800
Total Shaft Power, kW	1,870	1,870	1,860.

The maximum power output was 103.7% of the rated power output of 2,420 shp (1,804 kW). The design power limit was exceeded during these trials because the accurate setting of the thyristor control card could not be completed by PSNY personnel until after the trials.

STANDARDIZATION DATA TABLES

Standardization trials data are tabulated in Tables 4 through 7. Tables 4 and 5 list the English and metric standardization data for the even keel trim condition runs. Tables 6 and 7 list the English and metric standardization data for the trim by stern condition runs. Each table contains the true wind speed and direction, shaft speed, shaft torque, shaft power, and ship's speed. Data plotted in Figs. 3 through 6 are tabulated as spot averages and are listed on the right half of the tables. The spot average consisted of a three-pass spot where the mean of means method is used on three reciprocal passes. The average

speed for a spot is the speed through the water. These three-pass spot averages are required to eliminate the effects of wind, waves, and current.

One four pass speed spot was conducted. The four passes were conducted as a verification of the Even Keel maximum speed/power point.

CONCLUSIONS

1. The standardization trials showed that even keel (1 in. [2.5 cm] trim by stern) and trim by stern (12 in. [30.5 cm]) conditions provide identical speed and powering characteristics.
2. The maximum powering conditions are the following:

• Top speed, kn	12.36	
• Maximum average shaft speed, r/min	121.3	
• Total shaft torque, ft-lb (N-m)	108,800	(147,500)
• Total shaft power, shp (kW)	2,510	(1,870)
• Displacement, tons (t)	3,898	(3,960)
• Trim by stern, in. (cm)	12	(30.5)

3. The towed array deployed data showed that the ship requires about 23% more power to achieve a given speed with the array deployed, or that at a given power the ship loses about 0.8 kn speed with the array deployed.

ACKNOWLEDGMENTS

DTMB would like to thank the crew of USNS HAYES (T-AG 195) for their valuable assistance in the performance of the trials.

The author would like to thank Messrs. Everett Woo, Wayne Liu, George Brodie, John Webb, Andrew Kilpatrick, Shou-Jen Tsai, and Doug Griggs for their efforts and support during the trial and the report preparation period.

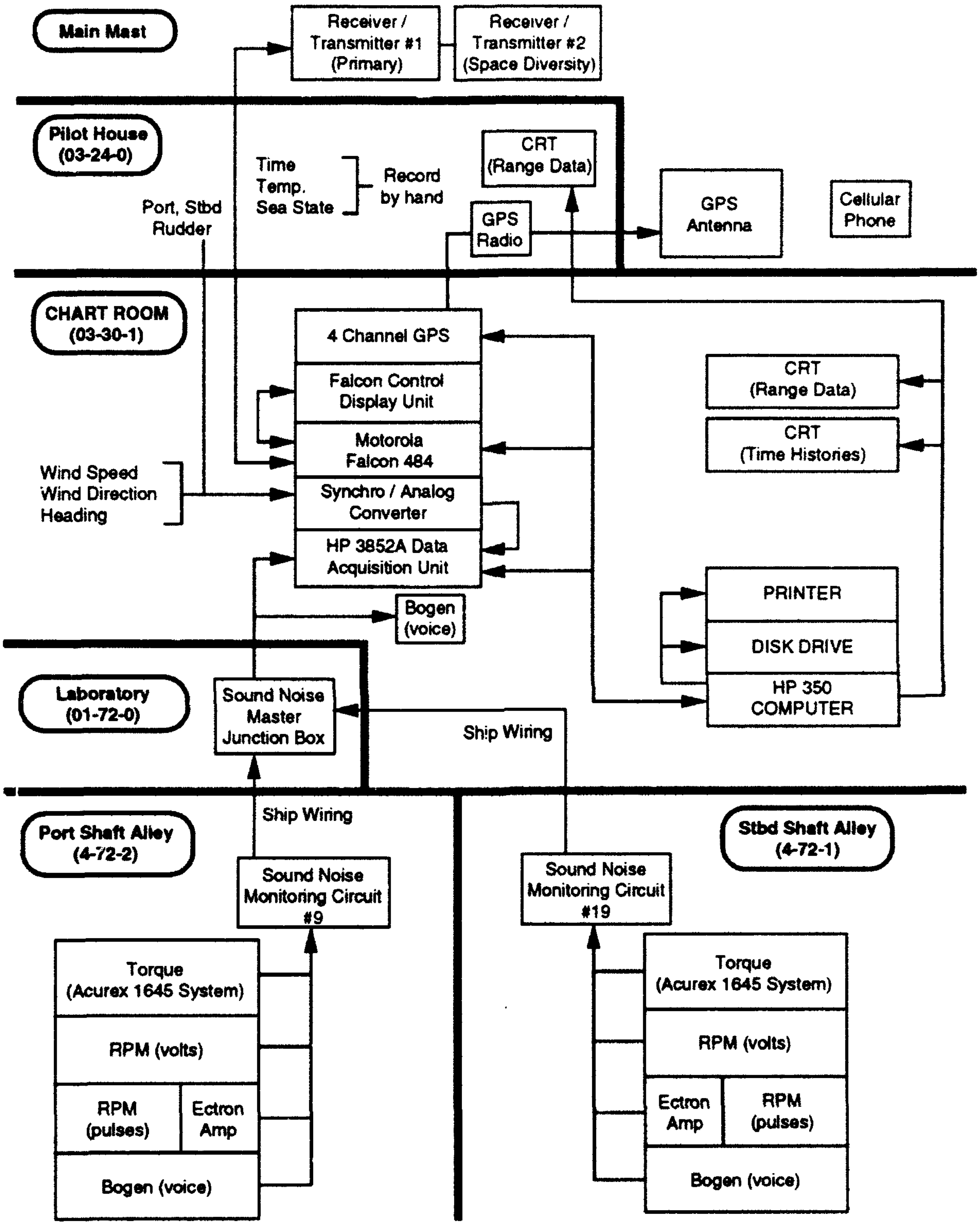

Fig. 1. USNS HAYES (T-AG 195) instrumentation block diagram.

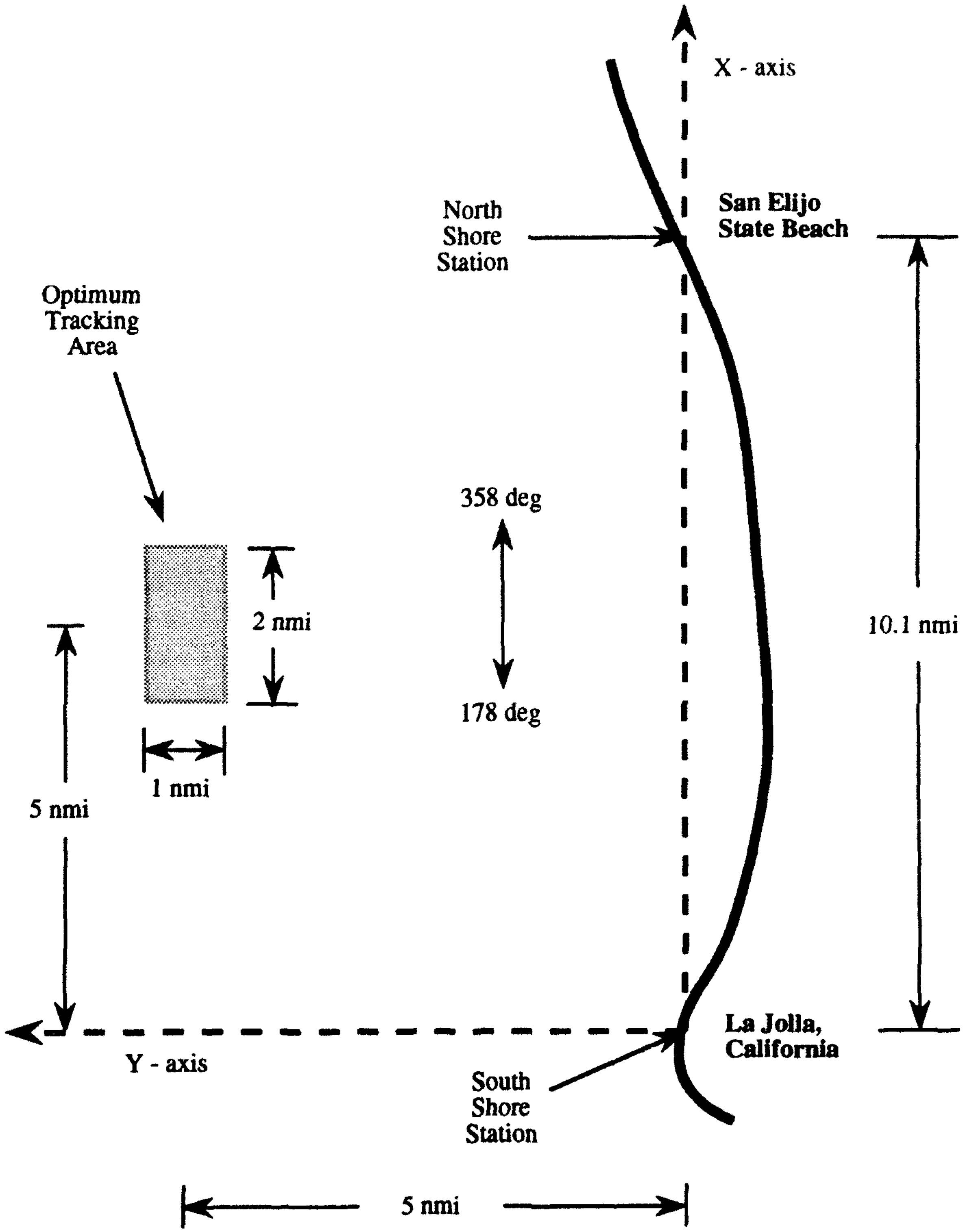

Fig. 2. La Jolla, California pulse radar tracking range.

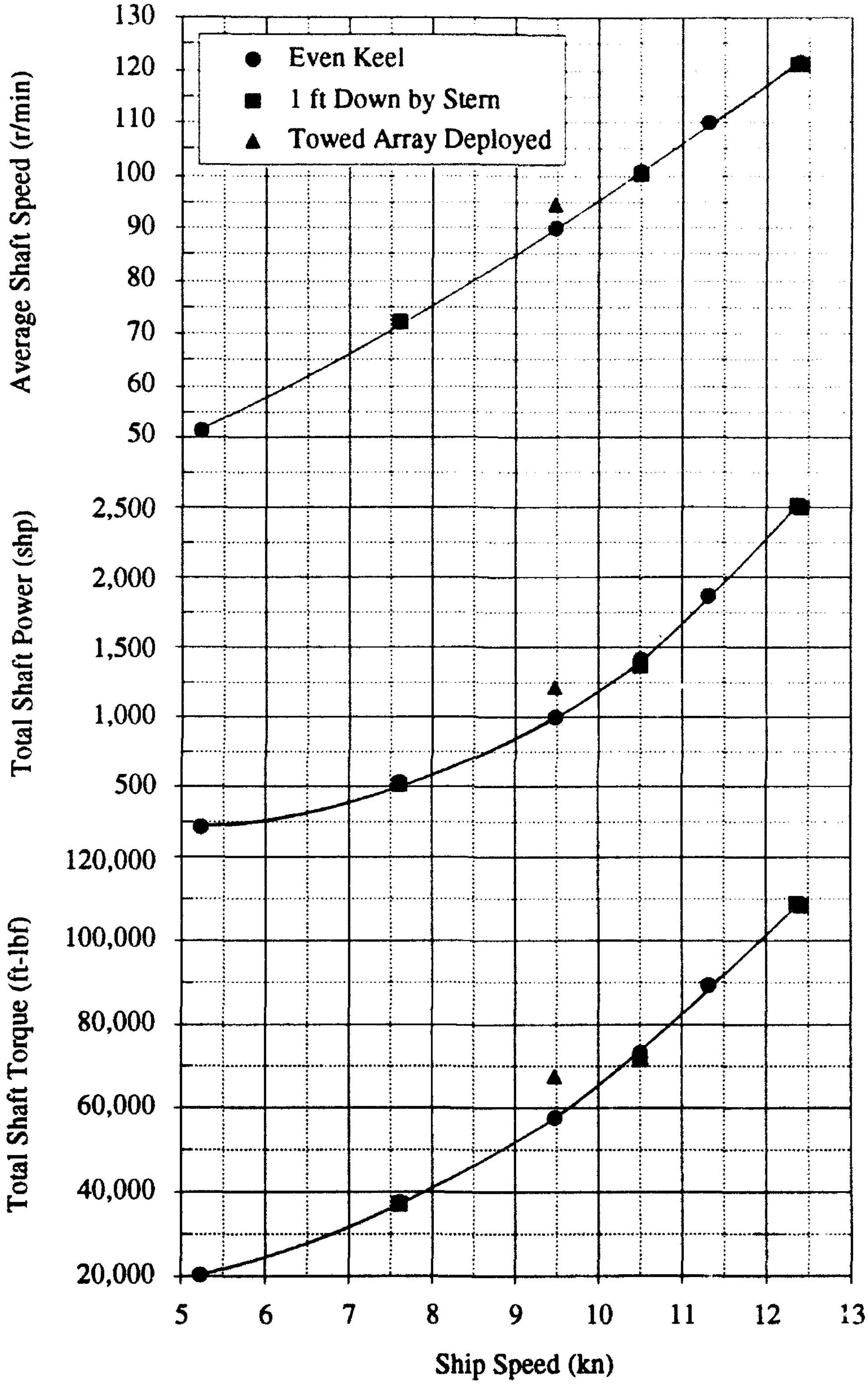

Fig. 3. USNS HAYES (T-AG 195) standardization trial results (English units).

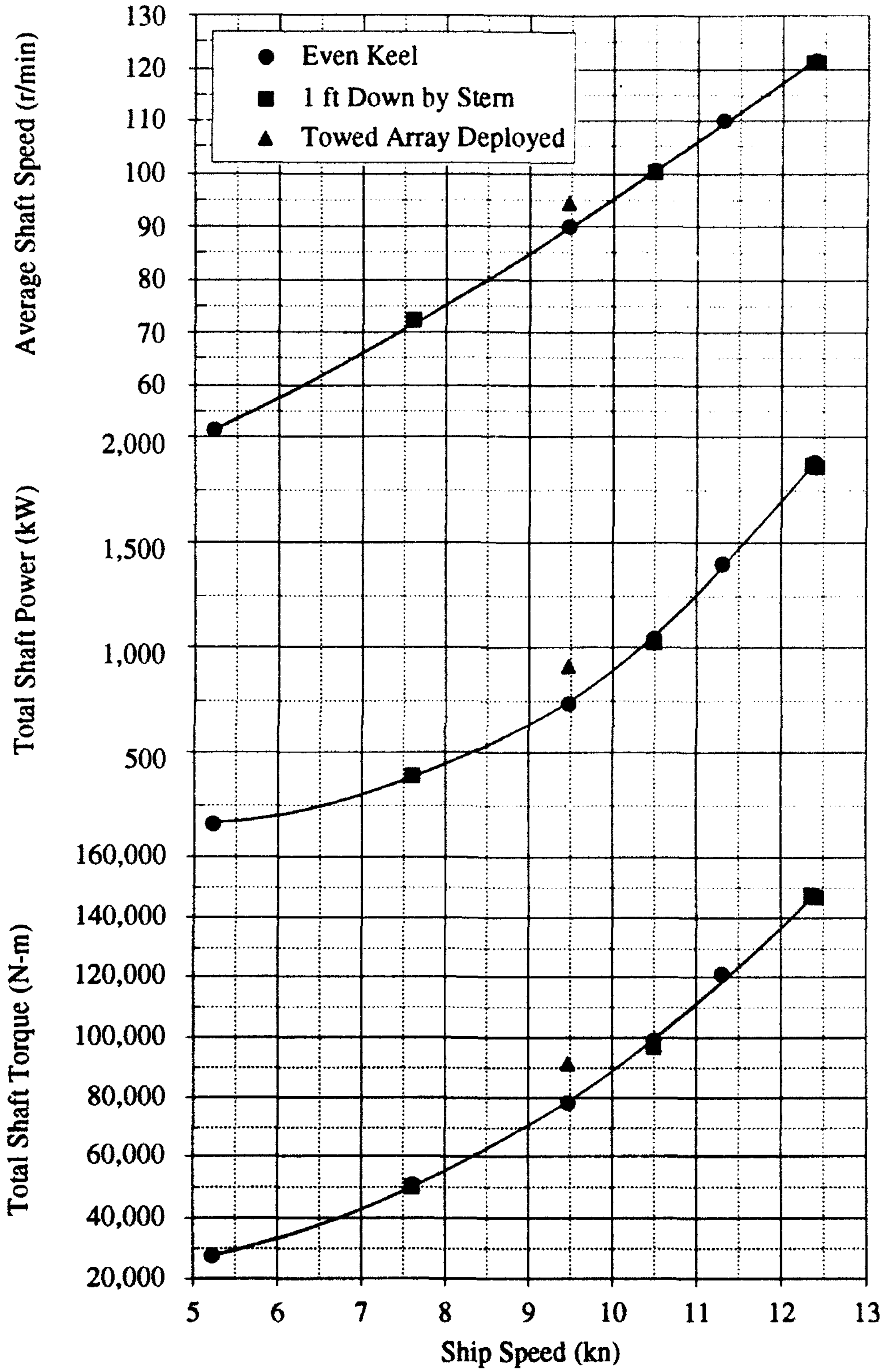

Fig. 4. USNS HAYES (T-AG 195) standardization trial results (metric units).

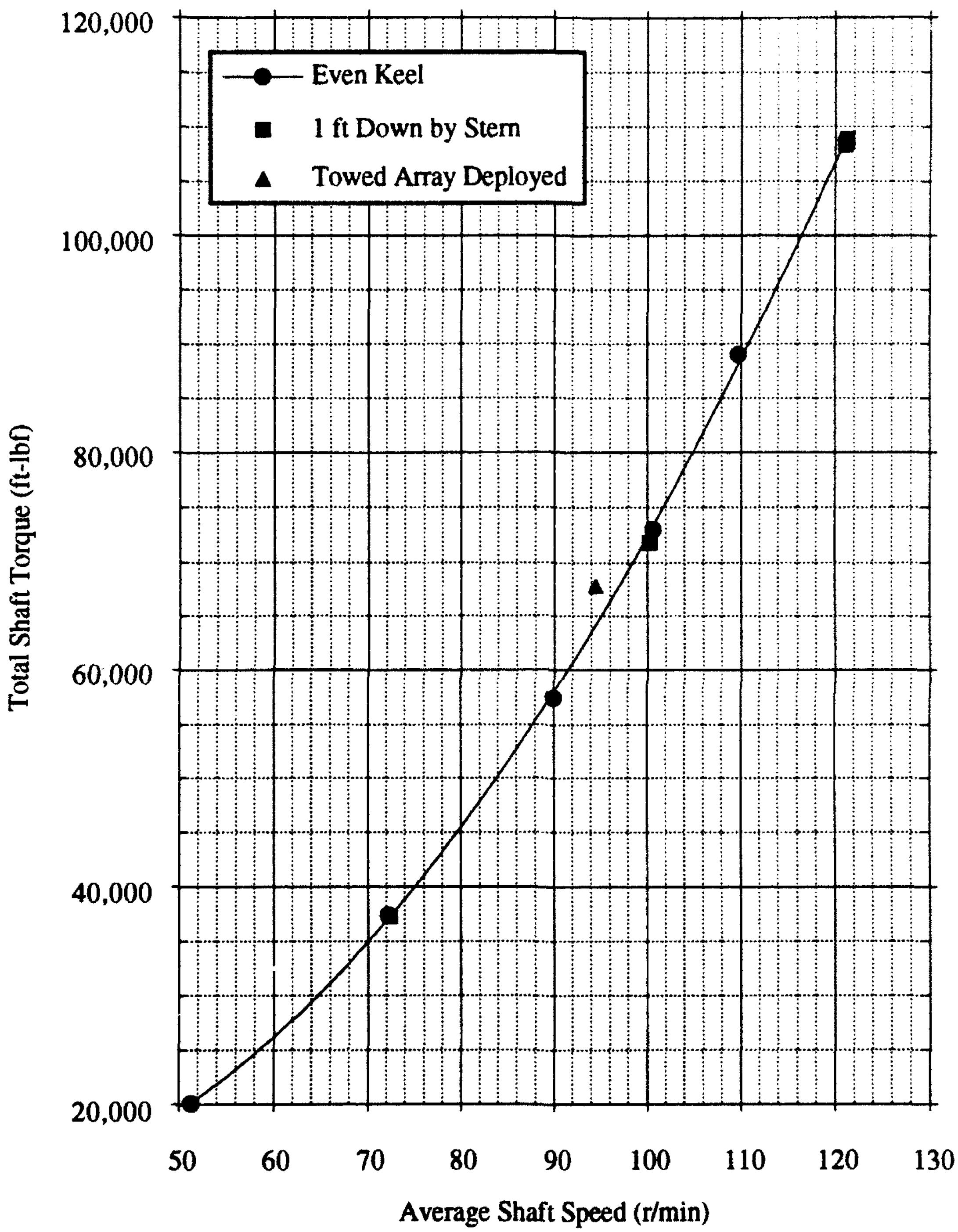

Fig. 5. USNS HAYES (T-AG 195) torque versus shaft speed for standardization trial results (English units).

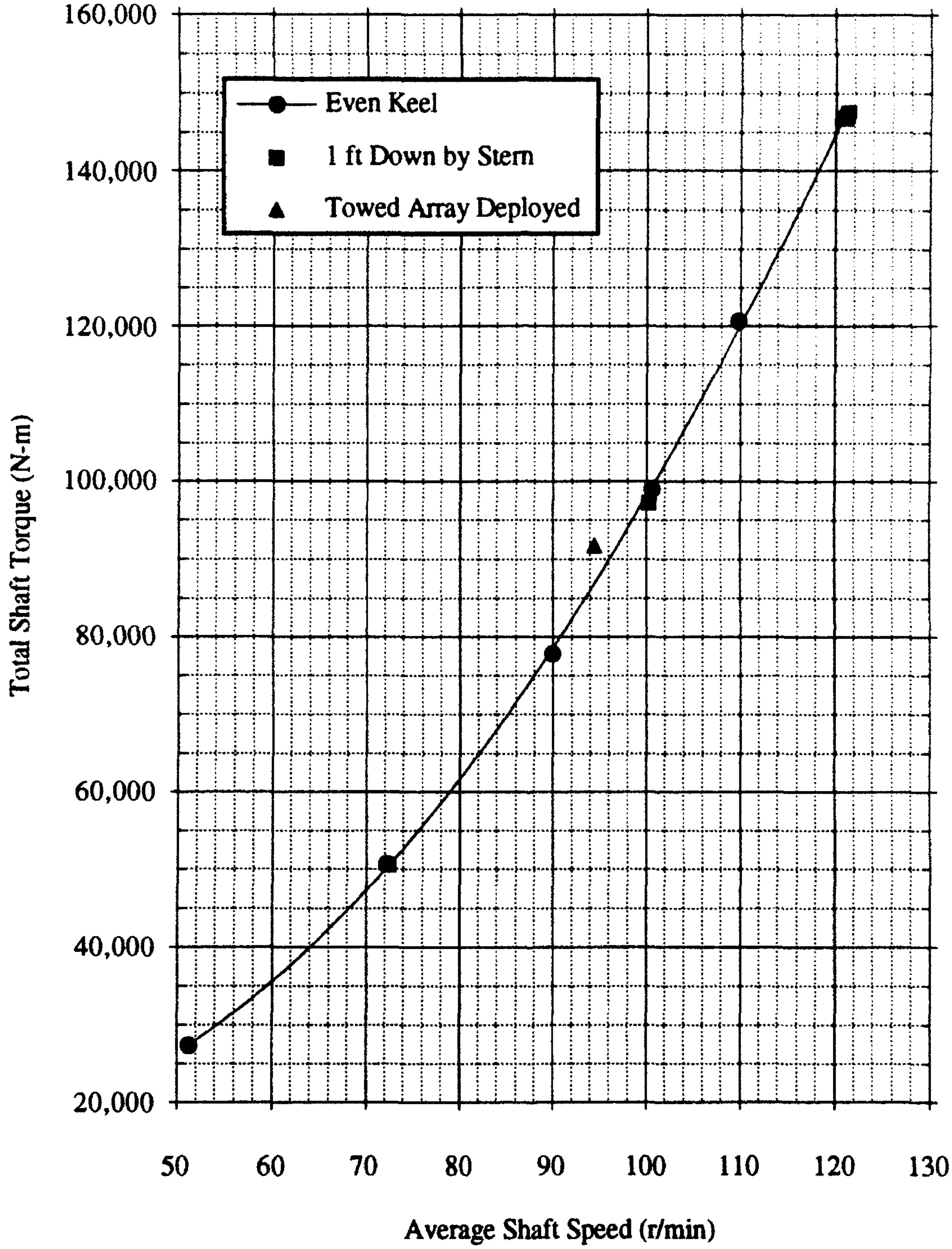

Fig. 6. USNS HAYES (T-AG 195) torque versus shaft speed for standardization trial results (metric units).

Table 1. USNS HAYES (T-AG 195) principal ship and propulsion shaft characteristics.

Ship Characteristics		
Length Overall (LOA), ft (m)	246.42	(75.11)
Length Between Perpendiculars (LBP), ft (m)	220.0	(67.06)
Beam, Maximum at DWL, ft (m)	75.0	(22.86)
Design Displacement, ton (t)	4,037	(4,102)
Design Total Shaft Power, shp (kW)	2,420	(1,804)
Power Plant	3 Caterpillar Diesel Engines (Model # 3516 DITA)	
Generators	Kato 1,150 kW (1,540 shp)	
Electric Motors (1 per shaft)	Manufactured by Westinghouse (Stbd Serial # 2001 AA)	
	(Port Serial # 2001 AB)	
Design Power per Motor, shp (kW)	1,200	895
RT/HLF Couplings	Manufactured by LO-REZ	

Propulsion Shaft Characteristics		
Number of Propeller Shafts	2	
Design Shaft Torque, ft-lb (N-m)	53,000	(71,858)
Design Shaft Speed, r/min	120	
Starboard Shaft Outside Diameter, in. (cm)	10.032	(25.481)
Starboard Shaft Inside Diameter, in. (cm)	2.932	(7.447)
Starboard Shaft Modulus of Rigidity, lb/in^2 (kPa)	12,270,000	(84,602,000)
Port Shaft Outside Diameter, in. (cm)	10.028	(25.471)
Port Shaft Inside Diameter, in. (cm)	2.954	(7.503)
Port Shaft Modulus of Rigidity, lb/in^2 (kPa)	12,176,000	(83,954,000)
Direction of Rotation	Outboard	

Table 2. USNS HAYES (T-AG 195) principal propeller characteristics.

Principal Propeller Characteristics		
Number of Propellers	2	
Manufacturer	Ferguson	
Material	Ni-Al-Br (ABS Type 4 MIL-P-21230 Alloy 1)	
NAVSEA Drawing Number	802-6118838	
Serial Number (Port)	19-87 (F2793)	
Serial Number (Starboard)	20-87 (F2794)	
Number of Blades	6	
Propeller Diameter, ft (m)	12.0	(3.66)
P/D at 0.7R	1.009	
Pitch at 0.7R, ft (m)	12.108	(3.69)
Chord at 0.7R, in. (cm)	33.84	(85.95)
Expanded Area, ft^2 (m^2)	70.26	(6.53)
Disc Area, ft^2 (m^2)	113.04	(10.51)
Projected Area ft^2 (m^2)	58.74	(5.46)
Projected Area / Disc Area	0.520	
Total Weight of Hub with Blades (dry), lb (kg)	10,317	(4,680)
Total Weight (wet) less Buoyancy, lb (kg)	9,043	(4,102)

Table 3. USNS HAYES (T-AG 195) standardization trial conditions.

Item	Even Keel		Trim by Stern	
Trial Date	23 October 1992		23-25 October 1992	
Time of Day	1544 to 2042		on the 23rd: 2218 to 2249 on 24-25: 2212 to 0013	
Trial Location	La Jolla, CA		La Jolla, CA	
Displacement, tons (t)	3,951	(4,014)	3,898	(3,960)
Trim by Stern, in. (cm)	1	(2.5)	12	(30.5)
Seawater Temperature	69°F	(21°C)	69°F	(21°C)
Seawater Specific Gravity	1.026		1.026	
Sea State	0 to 1		0 to 1	
Air Temperature	68°F	(20°C)	70°F	(21°C)
Avg True Wind Speed, kn	4 - 17		3 - 24	
True Wind Direction	28° - 292°		43° - 337°	

Table 4. USNS HAYES (T-AG 195) even keel standardization trial results, 23 October 1992 (English units).

Run No.	True Wind Speed (kn)	True Wind Direction (deg)	Shaft Speed Stbd (r/min)	Shaft Speed Port (r/min)	Shaft Torque (1645 System) Stbd (ft-lbf)	Shaft Torque (1645 System) Port (ft-lbf)	Shaft Power Stbd (hp)	Shaft Power Port (hp)	Ship's Speed (kn)	Average Shaft Spd (r/min)	Total Torque (ft-lbf)	Total Power (hp)
1010S	17	61	51.5	50.9	10,800	10,400	110	100	4.86	51.2	21,200	210
1020N	4	214	51.7	51.0	10,000	9,500	100	90	5.51	51.4	19,500	190
1030S	13	292	51.6	50.9	10,400	9,900	100	100	5.05	51.3	20,300	200
Avg									5.23	51.3	20,100	200
1040N	5	232	72.5	72.0	18,700	18,100	260	250	7.81	72.3	36,800	510
1050S	7	225	72.4	72.0	19,300	18,600	270	260	7.45	72.2	37,900	530
1060N	5	162	72.5	72.1	18,700	18,100	260	250	7.70	72.3	36,800	510
Avg									7.60	72.2	37,400	520
1070N	12	218	89.9	90.0	28,600	28,400	490	490	9.46	90.0	57,000	980
1080S	3	268	89.8	90.0	29,100	28,600	500	490	9.49	89.9	57,700	990
1090N	8	138	90.0	90.1	28,700	28,500	490	490	9.44	90.1	57,200	980
Avg									9.47	90.0	57,400	990
1100S	15	28	100.4	100.8	36,500	36,500	700	700	10.63	100.6	73,000	1,400
1110N	7	211	100.3	100.9	36,200	36,600	690	700	10.40	100.6	72,800	1,390
1120S	5	219	100.1	100.9	36,600	36,900	700	710	10.56	100.5	73,500	1,410
Avg									10.50	100.6	73,000	1,400
1130N	11	157	109.9	110.3	44,000	44,100	920	930	11.27	110.1	88,100	1,850
1140S	9	210	109.4	109.9	45,000	45,000	940	940	11.39	109.7	90,000	1,880
1150N	14	185	109.5	110.1	43,700	44,100	910	920	11.22	109.8	87,800	1,830
Avg									11.32	109.8	89,000	1,860
1160S	14	266	120.8	121.0	54,800	54,300	1,260	1,250	12.49	120.9	109,100	2,510
1170N	7	166	121.5	121.6	54,400	54,000	1,260	1,250	12.28	121.6	108,400	2,510
1180S	11	255	120.6	121.0	54,600	54,300	1,250	1,250	12.57	120.8	108,900	2,500
1190N	9	131	121.3	121.5	54,300	54,000	1,250	1,250	12.20	121.4	108,300	2,500
Avg									12.39	121.2	108,700	2,510

Table 5. USNS HAYES (T-AG 195) even keel standardization trial results, 23 October 1992 (metric units).

Run No.	True Wind Speed (kn)	True Wind Direction (deg)	Shaft Speed Stbd (r/min)	Shaft Speed Port (r/min)	Shaft Torque (1645 System) Stbd (N-m)	Shaft Torque (1645 System) Port (N-m)	Shaft Power Stbd (kW)	Shaft Power Port (kW)	Ship's Speed (kn)	Average Shaft Spd (r/min)	Total Torque (N-m)	Total Power (kW)
1010S	17	61	51.5	50.9	14,700	14,200	80	80	4.86	51.2	28,900	160
1020N	4	214	51.7	51.0	13,600	12,800	70	70	5.51	51.4	26,400	140
1030S	13	292	51.6	50.9	14,100	13,400	80	70	5.05	51.3	27,500	150
Avg									5.23	51.3	27,300	150
1040N	5	232	72.5	72.0	25,300	24,500	190	180	7.81	72.3	49,800	370
1050S	7	225	72.4	72.0	26,200	25,300	200	190	7.45	72.2	51,500	390
1060N	5	162	72.5	72.1	25,400	24,600	190	190	7.70	72.3	50,000	380
Avg									7.60	72.2	50,700	380
1070N	12	218	89.9	90.0	38,800	38,500	360	360	9.46	90.0	77,300	720
1080S	3	268	89.8	90.0	39,400	38,800	370	370	9.49	89.9	78,200	740
1090N	8	138	90.0	90.1	38,900	38,600	370	360	9.44	90.1	77,500	730
Avg									9.47	90.0	77,800	730
1100S	15	28	100.4	100.8	49,500	49,400	520	520	10.63	100.6	[illegible]8,900	1,040
1110N	7	211	100.3	100.9	49,100	49,600	520	520	10.40	100.6	98,700	1,040
1120S	5	219	100.1	100.9	49,700	50,000	520	530	10.56	100.5	99,700	1,050
Avg									10.50	100.6	99,000	1,040
1130N	11	157	109.9	110.3	59,700	59,800	690	690	11.27	110.1	119,500	1,380
1140S	9	210	109.4	109.9	61,000	61,000	700	700	11.39	109.7	122,000	1,400
1150N	14	185	109.5	110.1	59,300	59,700	680	690	11.22	109.8	119,000	1,370
Avg									11.32	109.8	120,600	1,390
1160S	14	266	120.8	121.0	74,300	73,700	940	930	12.49	120.9	148,000	1,870
1170N	7	166	121.5	121.6	73,800	73,200	940	930	12.28	121.6	147,000	1,870
1180S	11	255	120.6	121.0	74,000	73,600	930	930	12.57	120.8	147,600	1,860
1190N	9	131	121.3	121.5	73,600	73,200	940	930	12.20	121.4	146,800	1,870
Avg									12.39	121.2	147,400	1,870

Table 6. USNS HAYES (T-AG 195) trim by stern standardization trial results, 23-25 October 1992 (English units).

Run No.	True Wind Speed (kn)	True Wind Direction (deg)	Shaft Speed Stbd (r/min)	Shaft Speed Port (r/min)	Shaft Torque (1645 System) Stbd (ft-lbf)	Shaft Torque (1645 System) Port (ft-lbf)	Shaft Power Stbd (hp)	Shaft Power Port (hp)	Ship's Speed (kn)	Average Shaft Spd (r/min)	Total Torque (ft-lbf)	Total Power (hp)
1340N	4	72	72.6	72.0	18,800	18,200	260	250	7.23	72.3	37,000	510
1350S	3	71	72.6	72.1	19,100	18,400	260	250	7.92	72.4	37,500	510
1360N	4	103	72.7	72.2	19,000	18,300	260	250	7.34	72.5	37,300	510
Avg									7.60	72.4	37,300	510
1400S	2	260	99.6	100.1	35,500	35,800	670	680	10.72	99.9	71,300	1,350
1410N	2	266	99.9	100.8	35,800	36,100	680	690	10.23	100.4	71,900	1,370
1420S	2	273	100.1	100.9	36,000	36,100	690	690	10.75	100.5	72,100	1,380
Avg									10.48	100.3	71,800	1,370
1460N	3	74	120.5	121.3	53,700	54,200	1,230	1,250	12.00	120.9	107,900	2,480
1470S	24	337	121.0	121.3	54,400	54,100	1,250	1,250	12.75	121.2	108,500	2,500
1480N	3	69	121.0	121.3	54,200	54,000	1,250	1,250	12.08	121.2	108,200	2,500
Avg									12.40	121.1	108,300	2,500
1500N*	23	168	121.4	121.6	54,800	54,400	1,270	1,260	12.13	121.5	109,200	2,530
1510S*	17	299	121.0	121.3	54,500	54,200	1,260	1,250	12.59	121.2	108,700	2,510
1520N*	7	128	121.2	121.3	54,300	54,100	1,250	1,250	12.12	121.3	108,400	2,500
Avg									12.36	121.3	108,800	2,510
6010S**	15	315	94.3	94.7	33,900	34,200	610	620	9.36	94.5	68,100	1,230
6020N**	6	109	94.3	94.7	33,700	33,900	610	610	9.52	94.5	67,600	1,220
6030S**	14	43	94.3	94.7	33,800	33,900	610	610	9.38	94.5	67,700	1,220
Avg									9.45	94.5	67,800	1,220

* Conducted 23 October 1992.
** Towed array deployed.

Table 7. USNS HAYES (T-AG 195) trim by stern standardization trial results, 23-25 October 1992 (metric units).

Run No.	True Wind Speed (kn)	True Wind Direction (deg)	Shaft Speed Stbd (r/min)	Shaft Speed Port (r/min)	Shaft Torque (1645 System) Stbd (N-m)	Shaft Torque (1645 System) Port (N-m)	Shaft Power Stbd (kW)	Shaft Power Port (kW)	Ship's Speed (kn)	Average Shaft Spd (r/min)	Total Torque (N-m)	Total Power (kW)
1340N	4	72	72.6	72.0	25,400	24,700	190	190	7.23	72.3	50,100	380
1350S	3	71	72.6	72.1	26,000	24,900	200	190	7.92	72.4	50,900	390
1360N	4	103	72.7	72.2	25,700	24,800	200	190	7.34	72.5	50,500	390
Avg									7.60	72.4	50,600	390
1400S	2	260	99.6	100.1	48,100	48,500	500	510	10.72	99.9	96,600	1,010
1410N	2	266	99.9	100.8	48,500	49,000	510	520	10.23	100.4	97,500	1,030
1420S	2	273	100.1	100.9	48,800	48,900	510	520	10.75	100.5	97,700	1,030
Avg									10.48	100.3	97,300	1,020
1460N	3	74	120.5	121.3	72,800	73,500	920	930	12.00	120.9	146,300	1,850
1470S	24	337	121.0	121.3	73,700	73,300	930	930	12.75	121.2	147,000	1,860
1480N	3	69	121.0	121.3	73,500	73,200	930	930	12.08	121.2	146,700	1,860
Avg									12.40	121.1	146,800	1,860
1500N*	23	168	121.4	121.6	74,300	73,800	940	940	12.13	121.5	148,100	1,880
1510S*	17	299	121.0	121.3	73,900	73,500	940	930	12.59	121.2	147,400	1,870
1520N*	7	128	121.2	121.3	73,600	73,400	930	930	12.12	121.3	147,000	1,860
Avg									12.36	121.3	147,500	1,870
6010S**	15	315	94.3	94.7	45,900	46,400	450	460	9.36	94.5	92,300	910
6020N**	6	109	94.3	94.7	45,700	46,000	450	460	9.52	94.5	91,700	910
6030S**	14	43	94.3	94.7	45,800	46,000	450	460	9.38	94.5	91,800	910
Avg									9.45	94.5	91,800	910

* Conducted 23 October 1992.
** Towed array deployed.

APPENDIX A
INSTRUMENTATION AND MEASUREMENT UNCERTAINTY

INTRODUCTION

This appendix addresses the instrumentation, measurement descriptions and uncertainties. The measurements taken on each run during the trials were: shaft torque, shaft speed, ship's position and speed, relative wind speed, relative wind direction, ship's heading, and rudder position. Measurements were collected via an Hewlett Packard (HP) data acquisition unit and an HP computer. When appropriate, the measurements were converted to analog voltages prior to entering the data acquisition unit. The computer calculated the run averages as well as the maximum and minimum values. The data were also converted into engineering units and displayed in a hard copy format as output from a line printer. Figure 1 shows the data acquisition system used on HAYES.

MEASUREMENT DESCRIPTIONS AND UNCERTAINTIES

This appendix summarizes the instrumentation and the associated measurement uncertainties for sea trials conducted on HAYES in October 1992. A more detailed uncertainty analysis of typical full scale sea trial instrumentation can be found in the CARDEROCKDIV report on uncertainty analysis of full-scale trials by E.H. Johnson.[1] A general discussion of uncertainty analysis may be found in "Experimentation and Uncertainty Analysis" by H.W. Coleman and W.G. Steele.[2]

MEASUREMENT OF SHAFT TORQUE

Torque data were collected from the DTMB installed Wireless Data Corporation (WDC) 1645 torsionmeter systems. These signals were provided to the computer via the data acquisition unit.

The WDC 1645 torsionmeter system is a strain gage bridge monitoring system. A system was mounted on each propulsion shaft 2 ft aft of WT BHD 72 and 1 ft forward of the line shaft bearing (Port - Shaft Alley 4-72-2; Stbd - Shaft Alley 4-72-1). Two carrier rings were clamped on each shaft section and were used to transmit the torque on the shaft to a sensor bar clamped between the rings. The sensor bar is a sealed metal tube containing a strain gage bridge which produces a voltage directly proportional to the deflection of the bar. A stationary electronics unit provided voltage and current to drive the

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1. Johnson, Erik H., "Uncertainty Analysis of Standardization Trials on a Navy Fleet Oiler," CARDEROCKDIV report (in preparation).

2. Coleman, Hugh W., and W. Glenn Steele, "Experimentation and Uncertainty Analysis for Engineers," John Wiley & Sons, Inc. 1989.

rotating electronics and strain gage bridge. The output of the bridge was provided to a rotating low power transmitter. The transmitter signal was received, demodulated, and conditioned by the stationary unit, thus producing an analog voltage proportional to torque. These voltages were provided to the computer via the data acquisition unit.The modulus of rigidity for each shaft was measured with a Panametrics Ultrasonic Thickness Gage (Model 22DLHP) on 21 July 1992 at Puget Sound Naval Shipyard by two DTMB representatives.

The WDC torque measurement system was calibrated by subjecting the sensor bar to precise displacement increments. These displacements were related to shaft torque by known shaft properties such as outside diameter, inside diameter, and modulus of rigidity. These particular properties for the shaft sections where the WDC torque measurement systems were mounted are shown in Table 1. Table A.1 contains a repeat of this information for convenience sake and this table contains the other pertinent constants used in calibrating the torsionmeters. Discussion of bias and precision error estimates follow.

Table A.1. USNS HAYES (T-AG 195) torsionmeter constants.

	Port	Starboard
Design Shaft Torque (ft-lb)	53,000	53,000
Shaft Outside Diameter (in.)	10.028	10.032
Shaft Inside Diameter (in.)	2.954	2.932
Shaft Modulus of Rigidity (lb/in^2)	12,176,000	12,270,000
Ring Serial Number	147	148
Distance Between Knife Edges (in.)	17.633	17.656
Ring Bore (in.)	10.030	10.030
Sensor Serial Number	2-500	2-623
Receiver Card Serial Number	2-500	2-623
Sensitivity (lbft/mV)	10.600	10.600
Maximum Sensor Bar Deflection (in.)	0.00784	0.00778

Calculation of Bias Limit

To calculate the bias limit associated with measuring the deflection of the propulsion shafts and subsequently deriving the shaft torque, the bias errors associated with deflection of the shaft and acquiring the data (B_Δ) and the bias errors associated with calibration of strain-gage sensor bar (B_{SB}) must be calculated for each shaft:

			Port	Stbd
Bias of transfer standard, in.	B_{STD}	=	2.72×10^{-6}	2.71×10^{-6}
Bias of curve fit of calibration data, in.	B_{CF}	=	6.96×10^{-6}	10.28×10^{-6}
Bias of analog to digital conversion during calibration, in.	$B_{A/D1}$	=	0.40×10^{-6}	0.40×10^{-6}
Bias due to installation errors aboard the ship, in.	$B_{Install}$	=	7.34×10^{-6}	7.34×10^{-6}
Bias of analog to digital conversion during acquisition, in.	$B_{A/D2}$	=	6.38×10^{-6}	6.38×10^{-6}

			Port	Stbd
This results in a root-sum-square bias limit, in.	B_Δ	=	12.27×10^{-6}	14.41×10^{-6}.

The bias errors associated with the calibration of the strain-gage sensor bar (B_{SB}) are as follows:

			Port	Stbd
Bias of deflection (calculated from above section), in.	B_Δ	=	12.27×10^{-6}	14.41×10^{-6}
Bias of modulus of rigidity of the shaft, lbf/in^2	B_G	=	121,760	122,700
Bias of measurement of outside diameter of shaft, in.	B_{Do}	=	0.002	0.002
Bias of measurement of inside diameter of shaft, in.	B_{Di}	=	0.002	0.002
Bias of measurement of height of strain gage sensor	B_Y	=	0.001	0.001
Bias of measurement of distance between knife edges, in.	B_L	=	0.001	0.001.

By evaluating the partial derivatives of the data reduction equation and dividing by the result, then totaling the various elemental biases by the root sum square method, the total bias of the torque measurements are as follows:

			Port	Stbd
Total bias of the torque, lbf-ft	B_Q	=	654	656.

Calculation of Precision Limit

The total estimated precision limit for torque consists of two factors: the repeatability (P_{Qr}) of the data and the inherent unsteadiness (P_{Qt}) in the phenomena being measured. Three spots (10 runs) on HAYES were conducted at different times on the trial at identical nominal conditions. These data are an excellent example of repeatable test conditions and were used to evaluate the precision limit due to repeatability associated with collecting torque data. The average standard deviation (σ) of torque on all runs was used to determine the precision limit due to inherent unsteadiness. The average standard deviation of the port torque was 262 lbf-ft and for the starboard torque 270 lbf-ft.

			Port	Stbd
Precision limit due to repeatability, lbf-ft	P_{Qr}	=	323	723
Precision limit due to inherent unsteadiness, lbf-ft	$P_{Qt} = 1.96 * \sigma$	=	514	530.

The total precision limit is calculated by the root sum square method:

			Port	Stbd
Precision limit for torque, lbf-ft	$P_Q = \left(P_{Qr}^2 + P_{Qt}^2\right)^{1/2}$	=	607	896.

Calculation of Uncertainty

Analysis of torque measurement shows that for 95% coverage the uncertainty is equal to:

			Port	Stbd
Uncertainty, lbf-ft	$U_Q = \left(B_Q^{\;2} + P_Q^{\;2}\right)^{1/2}$	=	892	1,110
Percent of full torque (53,000 lbf-ft), percent		=	1.68	2.10.

MEASUREMENT OF SHAFT SPEED

Shaft rotational speed (r/min) was obtained using an infrared light sensor mounted adjacent to each shaft. A mylar band was wrapped around and secured to each shaft. Attached to this band were 30 equally-spaced pieces of reflective tape. As the shaft rotated, a pulse was generated each time a tape strip passed the sensor. The pulses were generated at a frequency directly proportional to shaft speed. This pulse train was converted to an analog voltage with a frequency to voltage (F/V) converter. These voltages were fed to the computer via the data acquisition unit.

Summary of Bias Error in Shaft Speed Measurement

Shaft speed is recorded using a frequency-to-voltage converter and 30 strips of reflective tape attached to the propeller shaft. There are five elemental bias errors associated with the shaft speed measurement:

			Port	Stbd
Bias of light strip position, r/min	B_{STD}	=	0.095	0.095
Bias of curve fit, r/min	B_{CF}	=	1.666	0.357
Bias of a/d during calibration	$B_{A/D\,1}$	=	6.72×10^{-6}	6.72×10^{-6}
Bias of d/a conversion, r/min	B_{CN}	=	60.23×10^{-6}	60.19×10^{-6}
Bias of a/d during acquisition, r/min	$B_{A/D\,2}$	=	83.87×10^{-6}	83.80×10^{-6}
This results in a root-sum-square bias limit, r/min	$B_{r/min}$	=	1.67	0.37.

Calculation of Precision Limit

The total estimated precision limit for shaft speed consists of two factors: the repeatability ($P_{r/min\,r}$) of the data and the inherit unsteadiness ($P_{r/min\,t}$) in the phenomena being measured. The same three spots (10 runs) that were used to determine the torque precision limit due to repeatability were used to determine the shaft speed precision. The average standard deviation (σ) of shaft speed on all runs was used to determine the precision limit due to inherent unsteadiness. The average standard deviation of the port shaft speed was 0.91 r/min and for the starboard shaft speed 0.81 r/min.

			Port	Stbd
Precision limit due to repeatability, r/min	$P_{r/min\ r}$	=	0.47	0.75
Precision limit due to inherent unsteadiness, r/min	$P_{r/min\ t} = 1.96*\sigma$	=	1.79	1.58.

The total precision limit is calculated by the root sum square method.

Precision limit for shaft speed, r/min

$$P_{r/min} = \left(P_{r/min\ r}^{\ 2} + P_{r/min\ t}^{\ 2}\right)^{1/2} = \quad 1.85 \qquad 3.06.$$

Calculation of Uncertainty

Uncertainty analysis of shaft speed measurement for this particular test shows that the uncertainty for 95% coverage is equal to:

			Port	Stbd
Uncertainty, r/min	$U_{r/min} = \left(B_{r/min}^{\ 2} + P_{r/min}^{\ 2}\right)^{1/2}$	=	3.10	2.47
Percent of maximum shaft speed (120), percent		=	2.59	2.05.

CALCULATION OF POWER

Now that the uncertainty of shaft torque and shaft speed have been determined, the uncertainty of shaft power can be determined. The equation to determine shaft power is:

$$SHP = \frac{Q * N}{5252}$$

where Q is shaft torque (lbf-ft) and N is shaft speed (r/min).

			Port	Stbd
Bias limit of shaft power, hp	B_{SHP}	=	23	16
Precision limit for shaft power, hp	P_{SHP}	=	28	31.

Uncertainty of shaft power for 95% coverage, hp

			Port	Stbd
	$U_{SHP} = \left(B_{SHP}^{\ 2} + P_{SHP}^{\ 2}\right)^{1/2}$	=	36	34
Percent of full power (1,210 hp), percent		=	3.01	2.85.

CALCULATION OF SHIP SPEED FROM POSITION DATA

The speed of the ship is calculated by a Motorola Falcon tracking system which determines the position of the ship relative to two fixed reference points. By knowing the position of the ship at a given time t_1, and knowing the position of the ship at a second time t_2, the speed of the ship over the ground

can be determined. A more complete description of the tracking range and coordinates can be found in Appendix B.

When V_k is calculated, it is determined by three methods. The first method employed is the instantaneous speed which is provided by the instrumentation. The second method calculates speed based on the first 10 positional fixes and the last 10 positional fixes. The third method calculates speed based on the first positional fix and the middle positional fix. All three calculated speeds are printed out so that they may be compared. A typical run is approximately 5-min long. One minute of approach data are collected followed by 4 min of actual run data. Calculated speed is based on the 4-min run period. At a speed of approximately 10 kn, a ship will travel approximately 1,352 yd in a 4-min period. This provides a fairly large change in position when calculating speed.

The system utilized to calculate speed can determine position to within ± 4 yd assuming adequate range geometry. Over a 1,352 yd distance, the maximum error between two positions is ± 4 yd. Therefore, this system provides a fairly good indicator of steady-state speed.

Calculation of Bias Limit

The method of calibration for the Falcon involved setting up the tracking equipment on a 2,187 yd runway. The distance had been surveyed and assumed to be accurate to within ± 0.4 yd. The equipment is then calibrated based on this distance. The tracking equipment is placed in the calibrate mode and the distance to be measured is input to the tracking instrumentation. The tracking instrumentation then outputs the measured distance that it has calculated. The difference between input and output distance is the calibration offset and that distance is stored in the tracking instrumentation memory.

The La Jolla, CA range is comprised of two sites; one on a lifeguard tower and the other on a tall condominium. The distance between the two sites has been surveyed and found to be 20,501. The bias due to calibration as discussed above is equal to:

Bias due to calibration, yd $B_{cal} = 4.0.$

Bias Due to Range Geometry

The positional accuracy is a function of the range geometry. The ideal range geometry is reached when the angle the ship makes with the two shore sites is 90 deg. As the ship moves down range, positional accuracy is degraded due to change in range geometry. The trial is conducted over a fairly small area of water approximately 1 nmi wide by 2 nmi long. The center of this target box is equidistance from both towers along the baseline and approximately 5 nmi west of the baseline. The towers are set so that the north tower is positioned on a bearing of 358 deg from the south tower. Because range geometry changes as the ship moves on the range, the positional error is taken to be:

Bias due to range geometry, yd B_{rg} = 4.0.

Bias Due to Calculated Velocity

Using partial derivatives of the velocity equation and the root sum square of B_{cal} and B_{rg} the bias of velocity due to calibration and range geometry is:

Bias of velocity due to calibration and range geometry, kn B_{V_r} = 0.06.

Calculation of Precision Limit

The total precision limit for speed as with the previous measurements, reflects the repeatability ($P_{V_{rr}}$) of the data and the range of scatter in data due to the unsteadiness (P_{V_t}) in the phenomena being measured. Standardization trials on the HAYES indicate that for a given powering condition, the precision limit due to repeatability is 0.01 kn. The average standard deviation (σ) of speed on all runs was used to determine the precision limit due to inherent unsteadiness. The average standard deviation of the ship's speeds was 0.05 kn.

Repeatability limit for speed, kn $P_{V_{rr}}$ = 0.01

Inherent unsteadiness for speed, kn $P_{V_t} = 1.96*\sigma$ = 0.10.

The precision limit is calculated using the root sum square method:

Precision limit for speed, kn $P_{V_r} = \left(P_{V_{rr}}^2 + P_{V_t}^2\right)^{1/2}$ = 0.10.

Calculation of Uncertainty

Uncertainty analysis of speed measurement shows the uncertainty for 95% coverage is:

Uncertainty for speed, kn $U_{V_r} = \left(B_{V_r}^2 + P_{V_r}^2\right)^{1/2}$ = 0.12

Percent of Full-Scale speed (12.40 kn), percent = 0.97.

SHIP'S SPEED BY DOPPLER LOG

The ship's DSN-450 Doppler Log system was not functioning properly throughout the trials. DTMB usually provides a calibration of this unit for the ship during trials. Unfortunately, this was an impossibility at this time.

MEASUREMENT OF WIND SPEED

Relative wind speed and direction were recorded from the ship's wind anemometers. The ship's anemometers are located well above the water line and are unobstructed by masts or antennae. Wind

speed output is a synchro voltage provided by the instrumentation. This synchro voltage is converted to an analog voltage using a synchro-to-analog voltage converter. Analog voltages from the anemometer were input to the computer as described above. Calculations were made, using the relative wind speed and direction along with the ship's speed and heading, to determine true wind speed and direction.

Uncertainty Due to Bias

The output from the synchro signal was fed into the synchro-to-analog converter. The following bias limits were determined for the wind speed measurement:

Input from wind tunnel, kn	B_{STD}	=	0.05
Synchro-to-analog conversion (± 0.150 deg of arc), kn	$B_{S/A}$	=	0.05
Voltmeter used during calibration (± 0.005 volts), kn	$B_{A/D\,1}$	=	0.03
Bias of curve fit, kn	B_{CF}	=	0.45
Bias of A/D during acquisition (± 0.008 volts), kn	$B_{A/D\,2}$	=	0.05
Total root-sum-square bias limit for wind speed, kn	B_{WS}	=	0.46.

Uncertainty Due to Precision

The precision limit for wind speed reflects the range of scatter in the data due to the actual unsteadiness in the phenomena being measured. The average standard deviation (σ) of wind speed on all runs was used to determine the precision limit due to inherent unsteadiness. During standardization trials on HAYES, the average standard deviation of wind speed was 0.62 kn.

Precision limit due to unsteadiness, kn $\quad P_{WS} = 1.96 * \sigma = \quad 1.21.$

Calculation of Uncertainty

Based on the above analysis, the uncertainty of wind speed measurement for 95% confidence is:

Uncertainty for wind speed, kn $\quad U_{WS} = \left(B_{WS}^2 + P_{WS}^2\right)^{1/2} \quad = \quad 1.29$

Percent of top speed of measured on trial (24 kn), percent = 5.39.

MEASUREMENT OF WIND DIRECTION

Wind direction is measured in the same fashion as the wind speed. Therefore, since it is the ship's system, a relatively high bias limit is assumed for the initial input.

Uncertainty Due to Bias

The output from the synchro signal was fed into the synchro-to-analog converter. The following bias limits were determined for the wind direction measurement:

Input based on visual sight, deg	B_{STD}	=	5.000
Synchro-to-analog conversion, deg of arc	$B_{S/A}$	=	0.150

Voltmeter used during calibration (± 0.005 volts), deg	$B_{A/D\,1}$	=	0.180
Bias of curve fit, deg	B_{CF}	=	0.288
Bias of A/D during acquisition (± 0.008 volts), deg	$B_{A/D\,2}$	=	0.288
Total root-sum-square bias limit, deg	B_{WD}	=	5.02.

Uncertainty Due to Precision

The precision limit for wind direction reflects the range of scatter in the data due to the actual unsteadiness in the phenomena being measured. The average standard deviation (σ) of wind direction on all runs was used to determine the precision limit due to inherent unsteadiness. During standardization trials on HAYES the average standard deviation of wind direction was 1.70 deg.

Total precision limit, deg $\quad P_{WD} = 1.96 * \sigma = 3.33.$

Calculation of Uncertainty

Based on the above analysis, the uncertainty of the wind direction measurement can be determined for 95% coverage to be:

Uncertainty for wind direction, deg $\quad U_{WD} = \left(B_{WD}{}^2 + P_{WD}{}^2\right)^{1/2} = 6.02$

Percent of full circle (360 deg), percent $\quad = 1.67.$

MEASUREMENT OF HEADING

Heading is determined by using the ship's gyro. Heading output is a synchro voltage provided by the ship's instrumentation. This synchro voltage is converted to an analog voltage using a synchro-to-analog voltage converter. The analog signal is then converted to a digital voltage and recorded on the acquisition computer.

Uncertainty Due to Bias

In order to calibrate the heading, the gyro is rotated from 0 deg through 360 deg. However, this was not possible on HAYES and the heading was calibrated underway by pointing the ship at various headings from 0 deg through 360 in increments of 45 deg. The corresponding output voltage is then recorded using a voltmeter. The gyro output was recorded from repeaters located on the ship's chart room just aft of the bridge. The output from the synchro signal was fed into the synchro-to-analog converter where it was then recorded using a voltmeter. The following bias limits were determined for the heading calibration:

Input from ship's gyro, deg	B_{STD}	=	0.200
Synchro-to-analog conversion, deg of arc	$B_{S/A}$	=	0.150
Voltmeter used during calibration (± 0.005 volts), deg	$B_{A/D\,1}$	=	0.180

Bias of curve fit, deg	B_{CF}	=	0.322
Bias of A/D during acquisition (± 0.008 volts), deg	$B_{A/D\,2}$	=	0.288
Total root-sum-square bias limit, deg	B_{Hdg}	=	0.53.

Uncertainty Due to Precision

The precision limit for heading reflects the range of scatter in the heading data due to the actual unsteadiness in the phenomena being measured. The average standard deviation (σ) of heading on all runs was used to determine the precision limit due to inherent unsteadiness. During standardization trials on HAYES the average standard deviation of heading was 0.41 deg.

Total precision limit, deg $P_{Hdg} = 1.96*\sigma$ = 0.80.

Calculation of Uncertainty

Based on the above analysis, the uncertainty of heading measurement can be determined for 95% coverage to be:

Uncertainty for heading, deg $U_{Hdg} = \left(B_{Hdg}{}^2 + P_{Hdg}{}^2\right)^{1/2}$ = 0.96

Percent of full circle (360 deg), percent = 0.27.

MEASUREMENT OF RUDDER

Rudder angle is determined by using the ship's rudder indicator. Rudder output is a synchro voltage provided by the ship's instrumentation. This synchro voltage is converted to an analog voltage using a synchro-to-analog voltage converter. The analog signal is then converted to a digital voltage and recorded on the acquisition computer.

Uncertainty Due to Bias

In order to calibrate the rudder angle signal, the rudder is moved from 30 deg right to 30 deg left. The corresponding output voltage is then recorded using a voltmeter. The rudder output was recorded from repeaters located on the ship's bridge and on the rudder stock. The output from the synchro signal was fed into the synchro-to-analog converter where it was then recorded using a voltmeter. The following bias limits were determined for the rudder calibration:

Ship's rudder indicator, deg	B_{STD}	=	0.500
Synchro-to-analog conversion, deg of arc	$B_{S/A}$	=	0.020
Voltmeter used during calibration (± 0.004 volts), deg	$B_{A/D\,1}$	=	0.020
Bias of curve fit, deg	B_{CF}	=	0.256
Bias of A/D during acquisition (± 0.005 volts), deg	$B_{A/D\,2}$	=	0.020
Total root-sum-square bias limit, deg	B_{Rud}	=	0.56.

Uncertainty Due To Precision

The precision limit for rudder reflects the range of scatter in the rudder data due to the actual unsteadiness in the phenomena being measured. The average standard deviation (σ) of heading on all runs was used to determine the precision limit due to inherent unsteadiness. During standardization trials on HAYES the average standard deviation of rudder was 1.12 deg.

Total precision limit, deg $\qquad P_{Rud} = 1.96*\sigma = \quad 2.19.$

Calculation of Uncertainty

Based on the above analysis, the uncertainty of rudder measurement for 95% coverage is:

Uncertainty for rudder, deg $\qquad U_{Rud} = \left(B_{Rud}^2 + P_{Rud}^2\right)^{1/2} = \quad 2.26$

Percent of rudder movement (60 deg), percent $\qquad = \quad 3.77.$

SUMMARY

A summary of the preceding discussion of USNS HAYES (T-AG 195) uncertainty is shown in Table A.2. The values in the table are for the worst case measurement uncertainties.

Table A.2. USNS HAYES (T-AG 195) summary of worst case measurement uncertainties.

Signal	Bias Limit	Precision Limit	Uncertainty	Percent
Shaft Torque (ft-lbf)	656	896	1,110	2.10
Shaft Speed (r/min)	1.67	1.85	3.10	2.59
Shaft Power (hp)	23	28	36	3.01
Ship's Speed (kn)	0.06	0.10	0.12	0.97
Wind Speed (kn)	0.46	1.21	1.29	5.39
Wind Direction (deg)	5.02	3.33	6.02	1.67
Heading (deg)	0.53	0.80	0.96	0.27
Rudder (deg)	0.56	2.19	2.26	3.77

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APPENDIX B
PULSE RADAR TRACKING RANGE AT LA JOLLA, CA

Tracking for the standardization trials was accomplished with a pulse radar (Motorola Falcon IV) system which included two shore based reference sites located in La Jolla, CA. The range and the locations of the shore based transponders can be found in Fig. 2.

The optimum tracking zone for the pulse radar system is depicted on Fig. 2 as a rectangle with dimensions of 1 by 2 nmi. The true heading of the baseline (X-axis) was determined from coordinate data to be 178° / 358°. Approach courses for all runs paralleled this heading and were conducted within or very near the optimum tracking rectangle. Geodetic data pertinent to the tracking range are shown below:

	South Site	North Site
Location	La Jolla, CA	San Elijo State Beach
Building	939 Condominium	Life Guard Station
Latitude	32° 50' 53"	33° 01' 00"
Longitude	117° 16' 35"	117° 16' 40"
X,Y Coordinates (yd)	0,0	20501,0
Height (yd)	30	7

These coordinate data were developed from tracking equipment calibrated between the surveyed South and North Sites. The surveyed coordinate data showed a known baseline distance of 20,501 yd between the two sites; this provided calibration data that was commensurate with the distances measured during the trials.

For these trials, the speed of the ship over the ground was calculated using positional values from the pulse radar system in the X direction only. As noted in Table A.2, the uncertainty of the speed measurement was ± 0.65 kn for these trials.

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APPENDIX C
DISPLACEMENT CALCULATIONS

The following discussion explains the procedure used for determining the displacement and trim of HAYES during the standardization trials.

Accurate visual draft readings were taken on HAYES on two occasions. Each time the readings were taken in San Diego Bay. The first were taken at noon on 23 October 1992 at the U.S. Naval Supply Center Fuel Annex just prior to departure for trials. These readings are deemed very reliable as they were read by a DTMB representative standing on the pier just after the ships lines were released. The water was very calm. These readings yielded a displacement of 3,951 tons. The second set of draft readings were obtained at about noon on 25 October 1992 at the U.S. Naval Supply Center just prior to the ship tying up at the pier. These readings are deemed very reliable as they were read by a DTMB representative standing on the pier and the water was very calm. These readings yielded a displacement of 3,898 tons. The specific gravity and temperature of the water were recorded at each pierside draft reading location. Tables C.1 and C.2 contain the draft readings, and the subsequent data and calculations required to determine the displacement and trim for the draft readings obtained.

Draft readings were attempted by small boat on the morning of 24 October 1992. However, getting an accurate draft reading was virtually impossible as the sea swells rolling past HAYES' draft marks made it extremely difficult to "choose" a number for a draft reading.

Note that a draft reading error of ±1 in. can result in an error of ±20 tons in total displacement.

The hydrometer used to measure the specific gravity was calibrated so that the specific gravity of fresh water at 60° F is 1.000. Therefore, in order to calculate displacement, the measured value had to be corrected for a sea water temperature of 69° F. The corrected specific gravity is shown in the tables.

Table 3 is a summary of HAYES' displacement and trim throughout the trial. The displacements and trim for the trials were the following:

	Even Keel Trials	Trim by Stern Trials
Displacement, tons	3,951	3,898
Trim by Stern, in.	1	12

Table C.1. USNS HAYES (T-AG 195) even keel standardization trial displacement calculations, 23 October 1992 at noon.

Draft Readings

Port		Starboard		Average		
Forward	= 22.58 ft	Forward	= 22.50 ft	(1)	Forward	= 22.54 ft
Transom	= 22.67 ft	Transom	= 22.58 ft	(2)	Transom	= 22.63 ft
Avg	= 22.63 ft	Avg	= 22.54 ft	(3)	Avg	= 22.59 ft

Trim by stern: 1 in.

Item #	Description	Value	
(4)	Specific Gravity of Water (Corrected for Water Temperature of 69° F)	1.025	
(5)	Specific Volume of Water	35.102	ft^3/ton
(6)	Forward Draft Mark to Ref. Line for Longitudinal Centers (F.P.)	4.33	ft
(7)	L.C.F. From Ref. Line at Draft From Hydrostatic Table	120.8	ft
(8)	Forward Draft Mark to L.C.F. = (7) - (6)	116.47	ft
(9)	Forward Draft Mark to After Draft Mark	215.67	ft
(10)	Trim Between Draft Marks = (2) - (1) (+ Aft, - Fwd)	+ 0.09	ft
(11)	Calculated Draft at L.C.F.	22.59	ft
(12)	Displacement in Seawater at Draft (11) From Hydrostatic Table	3,963	tons
(13)	List = 57.3 * [Port Avg - Stbd Avg] / 75.00 (+ Port, - Stbd)	+ 0.069	deg
(14)	Final Displacement = (12) * [35 / (5)]	3,951	tons

Table C.2. USNS HAYES (T-AG 195) trim by stern standardization trial displacement 25 October 1992 at noon.

Draft Readings

Port		Starboard		Average		
Forward	= 21.83 ft	Forward	= 21.83 ft	(1)	Forward	= 21.83 ft
Transom	= 22.67 ft	Transom	= 23.00 ft	(2)	Transom	= 22.84 ft
Avg	= 22.25 ft	Avg	= 22.42 ft	(3)	Avg	= 22.34 ft

Trim by stern: 12 in.

Item #	Description	Value	
(4)	Specific Gravity of Water (Corrected for Water Temperature of 69° F)	1.025	
(5)	Specific Volume of Water	35.102	ft^3/ton
(6)	Forward Draft Mark to Ref. Line for Longitudinal Centers (F.P.)	4.33	ft
(7)	L.C.F. From Ref. Line at Draft From Hydrostatic Table	120.69	ft
(8)	Forward Draft Mark to L.C.F. = (7) - (6)	116.36	ft
(9)	Forward Draft Mark to After Draft Mark	215.67	ft
(10)	Trim Between Draft Marks = (2) - (1) (+ Aft, - Fwd)	+ 1.01	ft
(11)	Calculated Draft at L.C.F.	22.37	ft
(12)	Displacement in Seawater at Draft (11) From Hydrostatic Table	3,910	tons
(13)	List = 57.3 * [Port Avg - Stbd Avg] / 75.00 (+ Port, - Stbd)	- 0.13	deg
(14)	Final Displacement = (12) * [35 / (5)]	3,898	tons

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APPENDIX D

PROCEDURES OF STANDARDIZATION TRIALS

Detailed descriptions of the procedures used for the standardization trials are given in this appendix. A definitive diagram of this maneuver is shown in Fig. D.1.

Ship speed and propeller shaft powering values for each data point (data spot) plotted were routinely determined by conducting three steady passes on the La Jolla, CA pulse radar tracking range. These passes were on reciprocal headings (358° - 178° true) with each pass about 4 min in duration (from COMEX to FINEX). A Williamson turn was conducted at the end of each pass to facilitate operating in the same body of water throughout a speed spot.

Each pass was initiated when ship and machinery conditions (torque and shaft speed) and ship speed had steadied. During the pass, DTMB installed shipboard equipment, tracked the ship's movements relative to two shore-based reference points, and recorded time and position data. Positional data were then matched against the propeller shaft powering conditions to define the ship's powering characteristics for each pass.

Speed values for each pass were determined by the ranging equipment and represented speed over the ground (speed through the water plus wind and current). Speed values for each data spot represented speed through the water; this value and the average powering characteristics for each spot were calculated by averaging data from the three passes with the data from the middle pass weighted twice. This procedure removed the effects of water current and wind on ship speed and is based on the assumption of a linear current versus time gradient throughout the duration of the spot. Unless otherwise noted, all references to ship speed imply spot speeds.

Effects due to current and wind were minimal and nonvarying relative to the time required to conduct a speed spot. Speed differentials between passes were generally between 0.0 and 0.7 kn throughout the trial period.

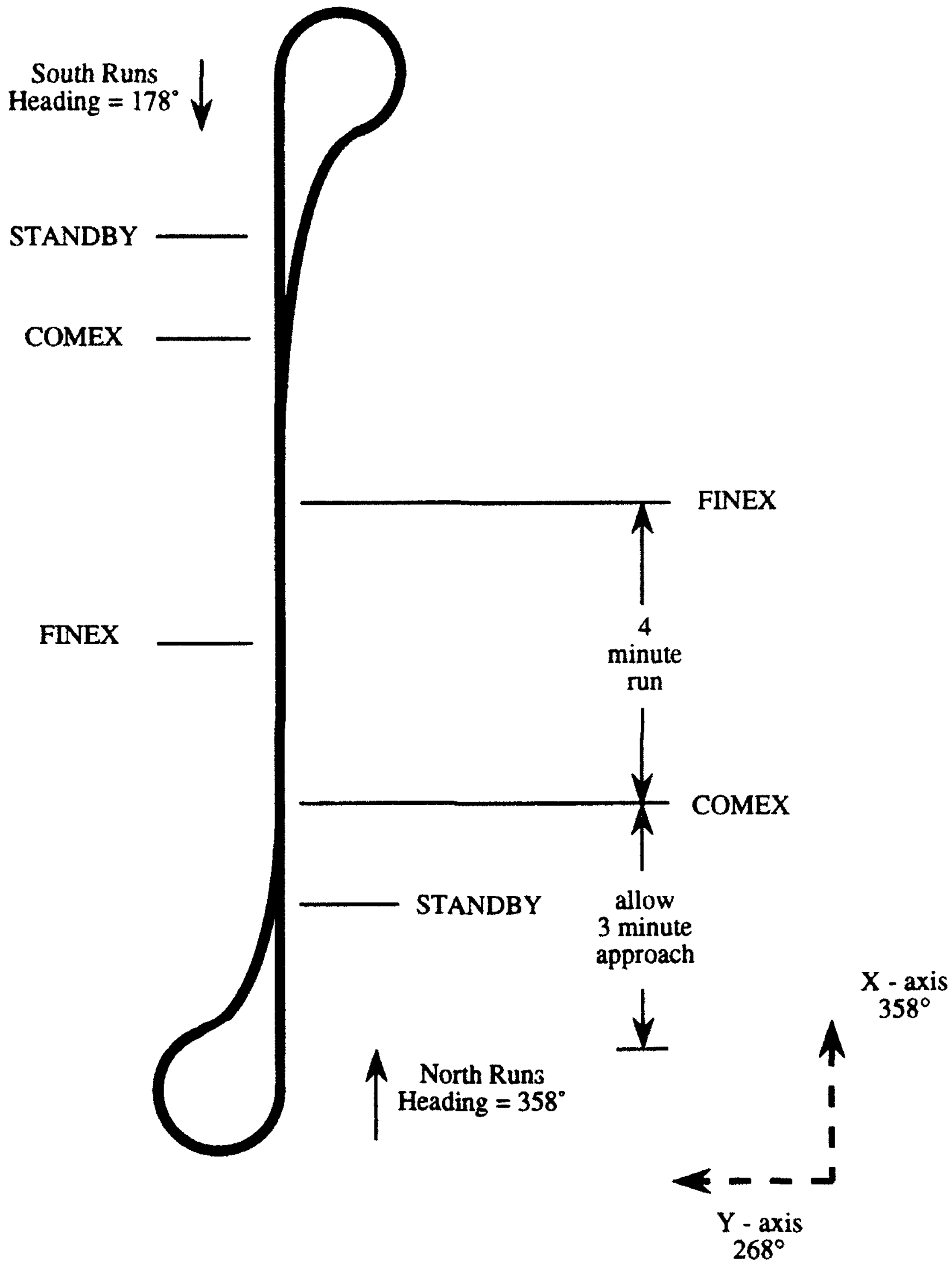

Fig. D.1. Ships path during a typical standardization run.

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